# ACOUSTIC FEEDBACK TRAINING IN ADAPTIVE ROWING

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## ABSTRACT

Acoustic information contributes to the timing of human movements as sound conveys time-critical structures subliminally. That is of crucial importance for the technique training in high performance sports, where a successful movement execution depends on the precision of modifying the movement. Particularly adaptive athletes with visual impairments or blindness have a special sensitivity to acoustic information. Yet still only few sports can be practised by athletes with visual impairments.

Since a concept of providing online acoustic feedback during on-water rowing training sessions was introduced and empirically investigated with elite athletes, it was assumed that adaptive athletes particularly could benefit in terms of an enhanced perception for the movement execution. This paper deals with the implementation of providing online acoustic feedback to adaptive athletes in elite rowing. The results of the data-capture as well as the athletes' subjective experiences with the sound during rowing were described.

## 1. INTRODUCTION

The importance and relevance of sounds that accompany the execution of movements in sport situations is incontestable and is, among experts, a crucial criterion for the evaluation of the quality of a movement. Use of the sense of hearing to get a feeling for the movement is not a new approach in principle and it would be almost trivial to say that everyday movements (as well as sports actions) are always accompanied by sounds. The loudness of a sound event is the physical consequence of the kinetic energy of a movement. For experts, sound is equally as significant as the sensation, at the very least sounds play an important role in the feel for the movement, mostly without being explicitly obvious.

That said, auditory evaluation is an indicator or performance benchmark for the feeling of the movement, especially in situations in which the sense of hearing/auditory processing is prevented during the execution of movements. Only when the sound is missing does its essential importance for the movement execution become evident. In its absence, any feeling for the resulting forces and their effect on the movement is lost. In rowing, it is the sound of the boat's forward motion that provides the athletes with information about the boat velocity.

Sounds have a quite different and particular relevance for people with visual impairments or who are blind, and who have a special sensitivity to sound and tactile information due to their limited visual perception.

Despite the advances in technology up to the present, only few sports can be practised by athletes with visual impairments. With the help of additional provided acoustic information, it is possible for them to compensate for their deficiency in visual information-processing without being overloaded in terms of perceptual aspects. For example, in precision sports such as in elite biathlon, the most important success factor is in the capacity of alternating the skills of physical endurance and shooting accuracy during the competition. Athletes are assisted by acoustic signals, which depending on signal intensity indicate when the athlete is on target. Taking advantage of auditory perception, athletes fixate the target by ear. A bleep-beep tone represents the closeness to the centre of the target: the closer the aim at the centre, the shriller the tone. Another example for a non-visual sport game is the paralympic ball game Goalball that was created especially for blind people and athletes with visual impairment. In doing so, basic ideas were used such as a sounding ball [1]. These sports demonstrate impressively the adapted perceptual skills of sportsmen using non-visual information and the possibility of participating in sport (and even ball games) without any visual information. AcouMotion, a system for acoustic motion control, was developed by utilising existing technological possibilities to represent data acoustically and by integrating the method of interactive sonification, with a first application called Blindminton, a sports game similar to Badminton but designed for people with visual impairment [2]. The system presents information on the position of a virtual ball by using sound. Based on this information the player is expected to play a ball with a virtual racket against a wall without dropping it on the ground. This enables the presentation of auditory information in a more systematic way as in existing sport games using natural sounds such as the ringing of a bell inside the Goalball [3]. Furthermore, AcouMotion offers the opportunity to test audiomotor performance and specific performance-determining skills such as the auditory-perception orientation in space.

These systems open new pathways in high performance sports for visual impaired athletes. By use of the sense of hearing, it is possible to assess the surrounding situation [4]. Whereas attention can be focused on specific aspects of a sound source among a mixture of multiple, coexisting sound sources in order to extract the relevant information. A speciality of auditory perception is not to hear everything but 'to know' what needs to be heard and what needs to be paid special attention. This so called Cocktail-party effect [5] enables the listener to change the focus of attention from one sound source to another without effort. In doing so, unimportant or disturbing noises or words (referring to conversation) are suppressed by focusing on the relevant information. Thus it is possible to perceive the interesting information as twice or three times as loud without turning the head [6].

Advantages of providing acoustic information about kinematic parameters in general as well as of the boat-acceleration time trace in particular have previously been described and empirically investigated in high performance rowing [7]. On the basis of these results and in order to support the feeling for the movement, as well as to provide an imagination of the duration of the movement and its execution for visual adaptive athletes, acoustic feedback is provided to elite adaptive athletes in on-water rowing training.

Special attention was paid to the effects subjectively perceived and athletes' reactions to the sound together with the results from data-capture, since even practising the sport is challenging for them. This is even more significant in situations with additional external influences during training such as the use of a test boat, measuring equipment and/or feedback-training methods. The use of synthetically produced acoustic information as a new training method is possibly even disturbing rather than beneficial for the execution of the rowing movement as athletes with visual impairment depend on auditory perception for their orientation. In comparison to sighted athletes it is not possible for them to subordinate the auditory sense.

This paper describes the results of providing acoustic feedback online during on-water training to adaptive athletes in elite rowing and their experiences subjectively perceived via the sound during rowing.

## 2. METHODS

### 2.1. Adaptive rowing

The regulations for adaptive rowing require that the crewmembers must have a handicap. In boat classes for more than two athletes, the crew must, more specifically, consist of athletes who are physically disabled as well as visually handicapped (part or blind). The crew studied consisted of two visual impaired athletes, one of whom was blind (100%) as well as of two physically handicapped athletes. The exceptional challenge for the blind athlete was his lack of rowing experience in terms of a perception as well as of a feeling for the rowing movement. The primary aim during the preparation phase for the adaptive world championships was set on synchronising the crew in a uniform rhythm in order to qualify for the Paralympic Games 2012 in London.

### 2.2. Characterization of the rowing stroke cycle

The rowing stroke is a cyclic motion sequence, separated into two main phases drive and recovery (or release), which are further subdivided into the front and back reversal (also known as the catch and finish turning points). With regards to the boat acceleration-time trace, the rowing cycle begins with minimal acceleration followed by a distinctive increase during the catch and the drive phase to the point of maximum boat acceleration. The end of the drive phase is represented by the next local minimum in acceleration. It is the transition phase where the oars were lifted out of the water (back reversal). The recovery phase begins subsequently to the transition phase with minimal acceleration amounts and ends a global minimum in acceleration. It is subdivided into a first and a second phase. The classification of the several phases in the rowing cycle is made in relation to a description of the rowing movement as well as to the executed technical skills.

The primary and overwhelming importance of the recovery phase with regards to the propulsive effect of the rowing cycle becomes manifestly clear. At the end of the drive phase, when the blades emerge from the water, the boat is released to run forward. This movement is challenging for the athletes after raising the oars out of the water, as they have to glide back up to the catch again in order to prepare the next stroke. Thus, it is important to execute the recovery phase without reversing the boat's momentum, that is, athletes' mass must be carefully moved by sliding towards the stern. This phase is critical for the boat velocity in particular, because fluctuations occur as a result of energy dissipations by jerky movements. Consequently, athletes should integrate the several parts of the rowing stroke into one movement that is as consistent and smooth as possible. This is especially important because one movement phase flows into the next one. However, when rowing at higher stroke rates it is not possible to strictly separate the single movement phases from each other.

### 2.3. Subjects

The athletes participating in the study were members of the German national adaptive rowing team (*N*=6), male (n=3) and female (n=3). The coxed four (LTA4+) was accompanied during on-water training sessions for two weeks and over a total of seven training sessions. For several reasons, it was not possible to train with the original crew for the whole time and so several times substitutes sat in four and came into contact with the sonification.

### 2.4. Measurement System

The acoustic feedback system *Sofirow* [8] (developed in cooperation with engineers from BeSB GmbH, sound and vibration, Berlin) [9] was used. The device measured the kinematic parameters: propulsive boat acceleration ($a_B$) with a micro-electro-mechanical (MEMS) acceleration sensor (sampling rate adjustable up to 125Hz) and boat velocity ($v_B$) with GPS (4Hz). Figure 1 showed the system and its position location on top of the boat.

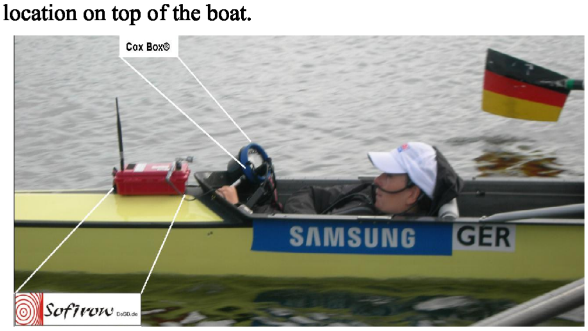


Figure 1: The acoustic feedback system *Sofirow*.

*Sofirow* converted the boat's acceleration-time trace online into acoustic information and transmitted the sound sequence via WLAN to the athletes in the rowing boat as well as to the coach into the motor boat. The sonification was presented in addition to the natural soundscape via loudspeakers of the inboard existing Cox Box® (Nielsen-Kellermann) through which the coxswain as well as the coach communicates instructions to the crew. Thus it was possible to listen to the sonification, to the coxswain as well as to the coach at the same time. In order to control the timing and the duration of the acoustic feedback, the sound could be selectively switched on or off by remote-control from the accompanying coaching boat.

In doing so, it was possible for the coach and the scientist to listen to the sonification while the athletes did not receive the acoustic feedback. Acoustic transmission was controlled by the scientist agreeing with the coach listening to the same acoustic feedback simultaneously with the athletes or alone.

The data storage on a SD-card made it possible to analyze the effect of the acoustic feedback on the boat motion in real time as well as to re-sonify the data subsequently.

### 2.5. Sound Design

The data-to-sound-transformation was achieved with the software Pure Data (Pd) as previously described and established in an earlier investigation with the German national rowing team in on-water training sessions. Using the sonification technique of Parameter Mapping [10], the boat's acceleration-time-trace was directly mapped to tones on the MIDI-scale and related to tone-pitch. In doing so, the data were transformed algorithmically into an audible sound in real time as a direct modulation. Consequently, tone pitch changed as a function of the boat's acceleration-time-trace and represented and differentiated between qualitative changes in the boat motion.

### 2.6. Test Design and statistical analysis

The investigation took place at the race course in Ratzeburg, Germany in August 2011 during the preparation phase for the adaptive world championships in Bled, Slovenia.

Prior to the first on-water training session, the athletes were introduced to the sonification in order to give them an idea of what they have to expect. Therefore, the sound sequence of a stored training run which was synchronized with a video was presented to the athletes. They could listen/watch to it as often as they needed.

The presentation of the acoustic feedback during on-water training was adjusted accordingly to the special needs of the athletes with visual impairments without overloading their environmental perception. Thus, the acoustic feedback was presented in up to 3 blocks per training session and for a total of 12 blocks. Each block consisted of 4 sections without and with the presentation of acoustic feedback in alternating order for the duration of 500m respectively.

In order to conduct an online analysis, the scientist and the coach listened to the sound result in the motorboat while the athletes did not receive any feedback. For the analysis, the sections were separated, consisting of a total of 30 rowing cycles each rowed at a comparable stroke frequency (±0.5 strokes per minute) for all sections.

Statistical comparison was achieved using an ANOVA (general linear model) with repeated measures (level of statistical significance was set at $p<0.05$) with the software SPSS 16.0. This procedure allows the test of interdependencies as well as of impacts (effects) from single factors between the sections studied. In order to rate the size of one factor or combination of factors, partial eta-squared ($\eta^2_p$) was calculated as the parameter of effect size. Partial eta-squared describes the effect size on the dependent variables according to the classification according to Cohen [11]. Post-hoc tests were used to rate the differences between the sections studied by comparing them pairwise. The statistical analysis considered the sections without and with acoustic feedback (AF), labeled as follows:

Baseline reference section (without acoustic feedback)
Section 1 (with AF)
Section 2 (without AF)
Section 3 (with AF)

Standardized questionnaires were taken in addition to examine the perception of adaptive athletes of the acoustic feedback in terms of its comprehensibility, correspondence with the rowing movement, its attention-guidance function for specific movement sections as well as potentially disturbing aspects.

## 3. RESULTS

The results of the investigation were described in separated subsections as follows: data-capture (3.1) describes the effects of acoustic feedback on the mean boat velocity; questionnaire (3.2) describes athletes' reactions to the sound and the effects subjectively perceived.

### 3.1. Data-capture

The results of the sections with acoustic feedback show that at training stroke frequency (SF 20 +/- 0.5 strokes per minute) there is a significantly increased mean boat velocity for the sections with sonification in comparison with the baseline (reference/control section) without sonification ($F_3=3.79$; $p=0.03$; $\eta_p^2=0.35$). The value for the effect size (partial eta-square) shows mid-level effect power.

According to the coach's GPS, the "*sections with the sonification were (...) faster with the sound*" and the crew "*moved away from the motorboat*". In particular, in the first section with sonification the mean boat velocity with acoustic feedback was increased ("*more clearly and better*"). In the subsequent sections without, with and without sonification the increases were less emphasized; the cox stated that the stroke frequency was however slightly increased ("*a frequency of 20 was more easily maintained with acoustic feedback than without. In the sections without the sonification it rose to 21 more often than with tone.*") With more training sessions in which the sonification was introduced, it was clear that the athletes were better able to achieve the increases in speed at a constant stroke frequency in the sections without sonification. The changes were most clear at the front reversal, which is represented in the sound sequence by a deep tone. With a movement executed too slowly, the tone is momentarily inaudible. The aim was to reduce the duration of the reversal movement by means of an uninterrupted sound-sequence.

In order to rate the difference between the sections studied, the results for the pairwise comparisons were considered. During both sections with acoustic feedback (section 1 and 3), the mean boat velocity increased significantly compared to the baseline (reference section) without. In contrast, the section without acoustic feedback (section 2) showed no significant differences to the baseline. The values for partial eta-square show high-level effect power for both sections with acoustic feedback (section 1 and 3) and mid-level effect power for the section without (section 2) (table 1).

Table 1: Test of contrasts (within-subjects) for the effect of acoustic feedback on the boat velocity in the different sections studied vs. the baseline: F-value (F), level of significance (p) and partial eta-square ($\eta_p^2$); degree of freedom=1; *N*=12.

| Sections | | $F_1$ | P | $\eta_p^2$ |
|---|---|---|---|---|
| | s1 (with) | 10.33 | 0.01 | 0.60 |
| Baseline | s2 (without) | 2.88 | 0.13 | 0.29 |
| | s3 (with) | 7.42 | 0.03 | 0.51 |

Figure 2 provides a visual impression of the differences measured between the sections with and without acoustic feedback in comparison to the baseline. As demonstrated in the figure (2), the sections with acoustic feedback showed a distinct increase in the mean boat velocity.

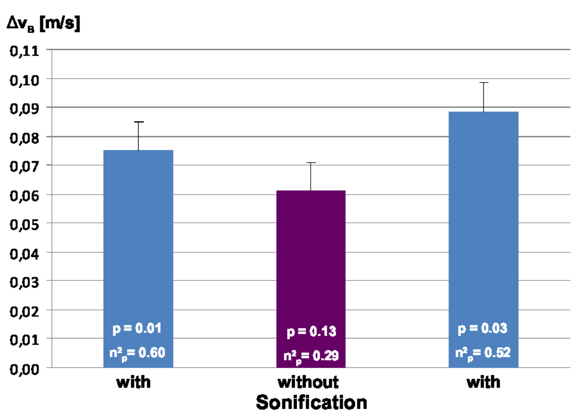


Figure 2: Mean differences and standard errors for the boat velocity ($\Delta v_B$) for the sections studied in comparison to the baseline.

### 3.2. Questionnaire

In reply to the question of what the athletes changed technically in terms of the movement execution, "*sliding forward gently*" and "*catches*" were emphasized and it was stated that they tried to keep the tone "*as constant as possible*" and "*maintained as long as possible before the entry of the blades*". For the coach, the efforts of the athletes were clear ("*the movement seemed smoother*" and that "*they could carry out the front reversal pretty well*").

The perception of the adaptive athletes when rowing with the sonification was "*initially irritating*" and "*confusing*", since the "*unusual type of training up to the present was not in use in normal training*". "*It had taken some time before I was used to the tone* (...) *until it had become a part of you*" (...) "*and after a familiarisation phase it was possible for us to improve the run of the boat.*" And "*as long as the toning does not overwhelm the background sounds which are for me important, it is helpful, and enables an improved check on the individual rowing technique,*" as well as a "*focussed improvement of the weak points in the movement.*" "*If I don't want to hear it, I can 'blank out' the tone.*" "*With regulated use in training, the toning is good*" but "*one must first learn to 'hear' it.*" "*If I can concentrate fully on the toning*" variations between individual strokes become clear. "*Extremely good for the forward sliding and fast catches or variations between them: absent tone with too slow catches/releases.*"

The procedure for the presentation of acoustic feedback was adjusted to the special need of adaptive athletes. This was confirmed with athletes' statements who appreciated the way of presentation as appropriately for on-water training sessions: "*In that way it was practised: very well for 500m-sections with and without tones in alternating order. It might be well to have two days of rest between the training sessions with the sonification.*" In order to be helpful the sonification should be used regulated in the training session because "*(...) if it is used overmuch, (...) the tone becomes annoying*". Here, too, it became evident that athletes do have individual strategies in dealing with the sound. "*I could have listen to it more times in order to fix it on my mind*" (…) "*for me as a sighted athlete, my own feeling for the boat run and the movement execution is more important*" (…) "*I would like to test it in the single sculls*".

The results underline previous findings and give support to our initial assumptions that acoustic feedback provides assistance for adaptive athletes to enhance their perception for executing the rowing movement more effective.

## 4. DISCUSSION

This paper described the results of providing acoustic feedback online during on-water training to adaptive athletes in elite rowing and their experiences subjectively perceived via the sound during rowing. It was aimed at enhancing athletes' perception for movement execution with the final aim to synchronise the crew in a uniform rhythm in order to improve the boat velocity by a reduction of intracyclic interruptions in the boat acceleration.

A theoretical basis for this concept as well as a design for a rowing specific acoustic feedback system has previously been described and empirically investigated with the German national rowing team [7]. With *Sofirow*, an acoustic feedback system, it is possible to provide the rhythm of the rowing cycle audibly by sonifying the boat acceleration-time trace. In doing so, changes in the measured acceleration trace were correlated to tone pitch: with increasing boat acceleration, the sound sequence increased in terms of tone pitch. Changes, that are normally invisible by watching the boat traveling through the water, became evident, as the differences were tiny but affect the boat motion importantly.

The acoustic feedback reflected overall effects of all external forces (water resistance, etc.) as well as athletes' movements acting on the system as a whole (boat and rower) by providing the boat acceleration time trace audibly. Athletes perceived the sound information of the movement patterns independently from vision and thus, the medium of presentation was supportive and enhanced their perception of the boat run. Interactivity of the perception process was allowed within the time frame of neuronal information acquisition and processing [12], and, as a result, the control of executing the movement was realizable in a time-uncritical way. In contrast to the coach's verbal instructions that sometimes need further explanations, the sound result was intelligible to all. Thus, the psychological interaction between the coach and athletes was bridged.

Owing to the direct coupling of tone pitch to changes in the boat's acceleration-time trace, the information contained in the captured-data became intelligible for the athletes, directly and intuitively and athletes perceived the single rowing cycle as a short sound sequence. Periodic recurrence of characteristic sections inside the rowing cycle represented the rhythm of the rowing cycle and awakened sensitivity for details in the sequence without further explanations needed. Awareness of the structure emerged solely from the knowledge of the movement and audio-visual interaction [13]. Rhythm is defined in movement science as a temporarily sequence of motor actions whose timing is of crucial importance for the movement execution [14]. It thus is inseparable from synchronization within moving contexts. Consequently, it was assumed that the measured improvement in the mean boat velocity was due to both, improved crew synchronization as well as due to improvement of the individual rowing technique of the athletes. This was confirmed due to athletes' individual statements.

With that, the results are similar in principle to previous findings in elite rowing training conducted with sighted and physical not handicapped athletes. Using the sonification as a new feedback method in the technique training of adaptive elite athletes in the four (LTA4+), it was possible to give support to the creation of an imagination of the movement as well as to the feeling for the rowing movement. The excited and keen interest of the coach and the crew in the sonification and its implementation into the technique training is promising for a regularly use in on-water training of adaptive athletes with the potential to expand it to other crews with a handicap. The feedback-training method will be an integral part for the preparation for the London 2012 Paralympic Games.

## 5. CONCLUSIONS

The acoustic feedback system *Sofirow* was developed to support the control of the rowing movement by the presentation of information that is provided through the sense of hearing in addition to existing sensory channels such as the visual sense. Thus, the device complements the feedback training in addition to existing feedback systems and provides relevant information for athletes with visual impairments. Captured sonified data of the boat's acceleration-time trace are stored as audio files (wav file format) and available for mental training. It furthermore contributes to previous research in rowing biomechanics [15], [16], [17] [18] and complements the existing visual analysis of the rowing technique used for the biomechanical diagnostic [19] with an expansion for the audible domain.

Desirable for the future is the willingness of the German Rowing Association (DRV) for funding adaptive athletes which is still reserved.

## 6. ACKNOWLEDGMENTS

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